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Technology for electronically varying helmet-visor tint

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ABSTRACT

Increasing interest in helmet-mounted displays (HMDs) has fueled research in variable transmittance visors (VTVs) because a VTV can reduce glare and increase HMD contrast in bright lighting conditions. The ideal VTV will be an electrically controllable light valve that allows the pilot to adjust visor transmittance (tint) to the level appropriate to the ambient lighting conditions. Liquid-crystal based devices can provide an efficient method for accomplishing this. Because flight helmets utilize polycarbonate visors, VTVs must be implemented on complex curved, plastic substrates. Liquid crystal devices, however, are typically implemented on flat glass substrates. We present a novel system, Variable Attenuation Liquid Crystal Device (VALiD), which can be utilized for this application. VALiD is a dichroic dye and liquid crystal based guest-host system. Our specific configuration allows for a fast system that fails to the clear state. Furthermore, the degree of polarization dependence can be tailored for use in different applications. VALiD has been implemented on thin, flexible, flat plastic substrates. Recently, this has been extended to doubly curved polycarbonate substrates and a prototype has been fabricated. In this paper we present the characteristics of this technology.

Keywords: liquid crystal, variable transmission visor, variable attenuation, ambient light control, helmet mounted display

1. INTRODUCTION

Helmet-mounted displays (HMDs) superimpose visual information on the pilot's panoramic view of his/her surroundings. The information must be legible to the pilot regardless of the intensity of ambient light, which may vary from direct sunlight to near total darkness. To provide an adequate contrast ratio, essential for reliable perception, either the intensity of the projected image carrying the information or of the ambient light reaching the pilot must be controllable. It can be difficult to produce sufficient display luminance under bright viewing conditions, so the more elegant approach is to adjust see-through transmittance. Ideally, this adjustment should occur automatically as the lighting conditions change; there should also be a manual adjustment that allows the pilot to tailor the system to his/her preference. The device needs the following characteristics: it should

i. have adjustable attenuation controllable by the operator
ii. be colorimetrically neutral across the visible spectrum
iii. have response time comparable to that of the human iris (<1 s)
iv. transmit a clear image (no haze) at all levels of attenuation
v. fail to the clear state, i.e., the visor must become transparent, rather than dark, if the device fails
vi. be compatible with conventional plastic helmet visors
vii. have low power consumption
viii. be UV resistant
ix. show low thermal sensitivity.

The darkening properties of simple photochromic materials cannot be controlled by an operator, which makes them unsuitable for this application. Because of their unique optical properties, liquid crystals offer the possibility of low cost, lightweight methods for efficient light control. Conventional liquid crystal technologies offer means of achieving these goals. However, they are implemented on glass substrates. To date, there has been no commercial liquid crystal device on curved plastic substrates.

We have developed and demonstrated a Variable Attenuation Liquid Crystal Device (VALiD) consisting of a dichroic dye (DD) dissolved in a liquid crystalline host material. The system addresses and meets the requirements presented above. We

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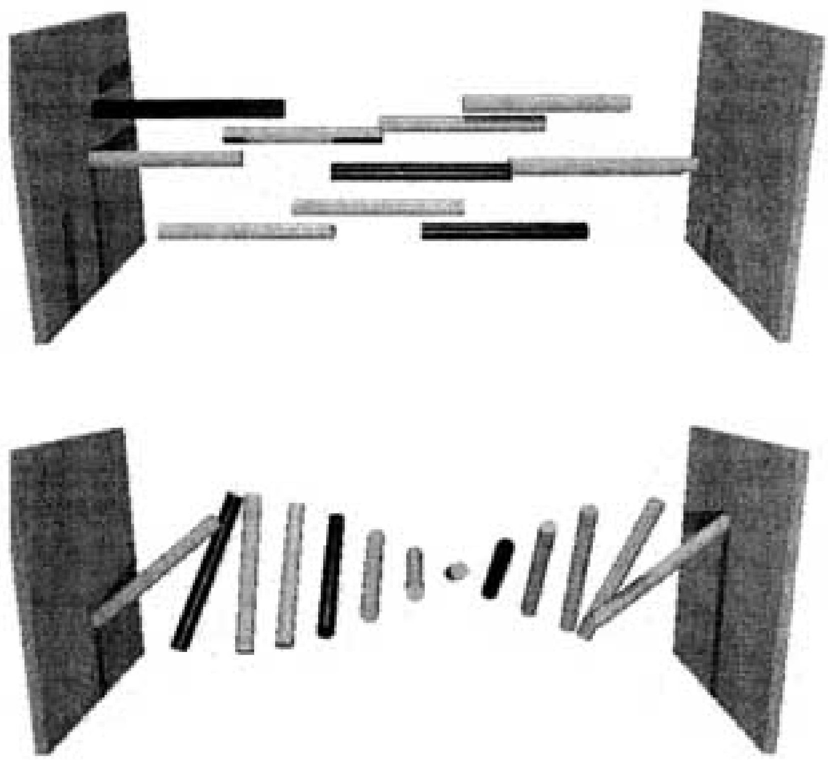
modeled and prototyped several cells using a fails-clear geometry. The device shows a fast, colorimetrically neutral, clear response across the visible spectrum. Further, we demonstrated the technology is compatible with using plastic substrates. Recently, we have been successful implementing it as a Variable Transmittance Visor (VTV) on doubly curved polycarbonate visors.

2. GUEST-HOST SYSTEM CONFIGURATION

Design of the system configuration for the Variable Attenuation Liquid crystal Device (*VALiD)* was based on the requirements presented above. Conventional liquid crystal devices utilize the birefringence properties of the host sandwiched between two polarizers. However, these systems are not suitable for HMDs due to shortcomings in using polarizers, such as clear-state transmission and viewing angle dependence. Therefore, a dichroic-dye liquid-crystal guest-host system was chosen for implementation. In dichroic dyes, the absorption cross-section depends on the relative orientation of the dye to the incident field polarization. This dependence can control light transmittance by use of a liquid crystal host to align the dye. By changing the orientation of the liquid crystal, the orientation of the dye and, hence, the absorption and attenuation of light can be controlled. Without the use of polarizers, changes in the transmittance are primarily due to the dye because liquid crystal's absorption is in the UV. This system can be designed to have a high clear-state transmission and little viewing angle dependence. Furthermore, suitable combinations can be formulated to yield a colorimetrically neutral system. The switching speed for such a system is dictated by the response of the liquid crystal, which is in millisecond regime. To maintain clarity at all levels of attenuation, it is necessary to minimize light scattering. This requirement suggests the system cannot be constructed using PDLC- or NCAP-based devices, which exhibit haze in all transmission states. Conventional liquid crystal devices can be made to satisfy these conditions. However, they have not been, till now, compatible with plastic substrates. In addition, the severe curvature of the helmet-visor substrates would make conventional processing impossible. The issue of compatibility with curved plastic substrates is addressed in subsequent sections.



(a)

(b)

Figure 1. Geometry for FC-VALiD in (a) unpowered, (b) powered states. Application of voltage results in orientation of LC perpendicular to the surface normal. Note that the LC can exhibit a twist in the powered state.

In principle, it is possible to design a configuration that is non-absorbing in the unpowered state and returns to this configuration in the event of power loss. The orientation of the liquid crystal, and therefore the guest dye, depends on the magnitude of the applied voltage, enabling continuously variable attenuation. Polarization dependence of the transmittance can be controlled by using a twisted liquid crystal configuration. The ratio of the pitch of the twist to the wavelength of light determines the extent to which the system response is polarization dependent. Stress relaxation in liquid crystals typically results in little or no haze.

To obtain a fails-clear configuration, it is necessary for the dye absorption to be minimal in the relaxed state. This can achieved by either the use of (i) liquid crystal with positive dielectric anisotropy and a negative dichroic dye or (ii) liquid crystal with negative dielectric anisotropy and a positive dichroic dye. The surface alignment needed for the first option is plannar; the second option requires homeotropic alignment. We have found that greater transmittance in the clear state can be obtained if we use the latter geometry. Figure 1 shows the liquid crystal and dye configuration in the unpowered and powered states. The system presented was named Fail-to-Clear VALiD (FC-VALiD).

Several cells were fabricated based on the above configuration. The cells were made using flat glass substrates. ITO coated substrates were coated with a homeotropic alignment layer and cured at 200° C. They were then assembled with 5-micron spacers and filled a variety of liquid crystal mixtures. The performance of the system was tested for a variety of dye and chiral concentrations. Figure 2 shows the wavelength dependence of the transmission in the powered and unpowered states for the FC-VALiD configuration. It can be seen that the transmission decreases with voltage and the absorption spectrum can be made colorimetrically neutral.

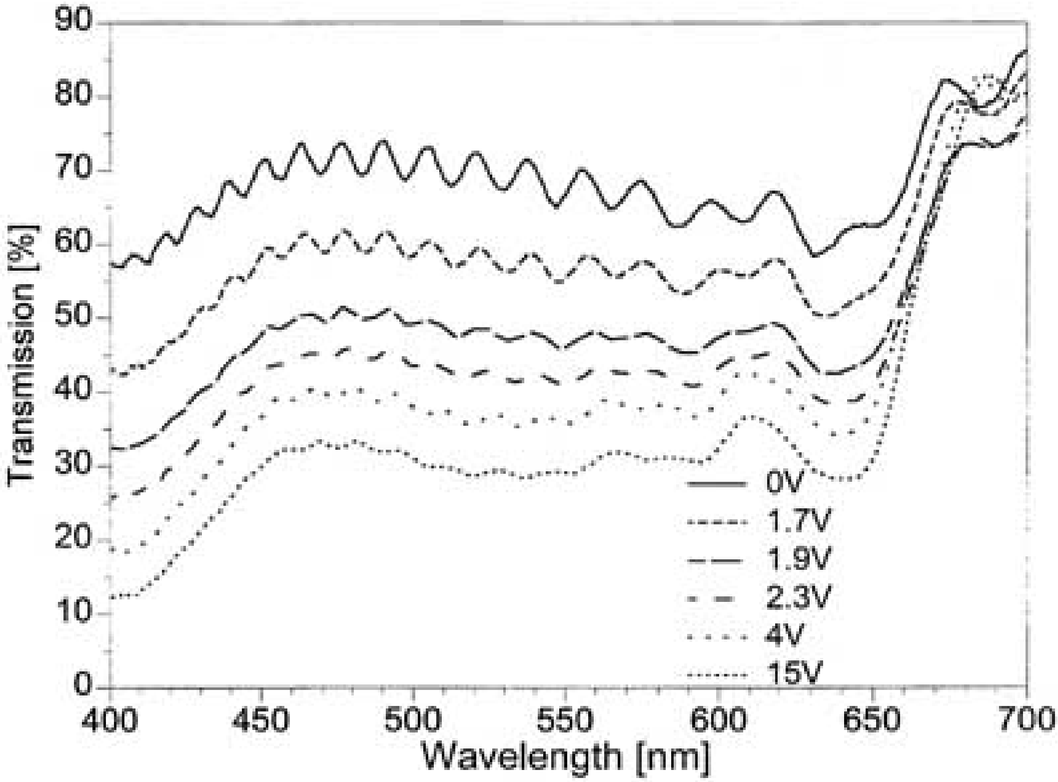


Figure 2. Wavelength dependence of the transmission of FC-VALiD. Note that the transmission is greater in the unpowered state and the device is colorimetrically neutral.

To date, we have constructed FC-VALiD devices with the transmission window of 60%-15% required by the US Air Force for daytime visor use. This system is polarization independent and meets all the requirements presented above. Currently, emphasis is placed in increasing the clear-state transmission in these systems while maintaining the 15% transmission in the maximum powered state.

3. CURVED PLASTIC SUBSTRATES

Testing of the FC-VALiD configuration and optimization of the relevant parameters were performed using flat glass substrates. Ultimately, however, the system must be implemented on Air Force issued visors. In particular, the final FC-VALiD must be implemented on large area, doubly curved, polycarbonate plastic. Current liquid crystal devices are based on flat glass substrates. Therefore, it was necessary to perform a significant redesign on the conventional processing techniques for liquid crystal based devices. The progression from flat glass to doubly curved plastic was divided into five stages. The first involved the use of flat glass to develop and test appropriate processing materials relevant to plastic substrate processing. Issues that were considered included the glass transition temperature of plastic substrates, chemical reactivity of processing material, and curing temperatures of the alignment layer. Furthermore, processing parameters such as alignment layer thickness and spacer deposition were tested for FC-VALiD with glass substrates. During the second stage, the system was implemented on flat plastic substrates. The materials and processing parameters obtained were used to test FC-VALiD on flat PET substrates. This choice of substrate was dictated by the commercial availability of ITO-coated plastic. ITO-coated PET substrates were cut and cleaned using an ultrasonic cleaner. A homeotropic alignment layer was spun onto the substrates and allowed to cure. The substrates were assembled using 5-micron spacers and vacuum filled. The electro-optic properties of the FC-VALiD were used to investigate the processing parameters, such as alignment layer uniformity and spacer density. The materials and processes identified during the first stage were re-examined and optimized.

Cylindrical VALiD can be achieved by either using two conformal cylindrical substrates or two flexible flat substrates. We decided to use flat substrates because the processing techniques developed earlier would require less modification. Therefore, this stage involved implementation of material and processing on flexible PET substrates. The substrates used were 7-mil, ITO-coated PET from Cortauld plastics. The substrates were cleaned and coated with a homeotropic alignment layer using spin coating techniques. They were then assembled using 5-micron spacers and sealed with a UV-curable epoxy. The cell was vacuum-filled with a mixture of liquid crystal and a Mitsui S-428 black dichroic dye. The cells showed flexibility and were conformed to the cylindrical shape of the Army SWD goggles. Figure 3 shows the FC-VALiD based goggles obtained.

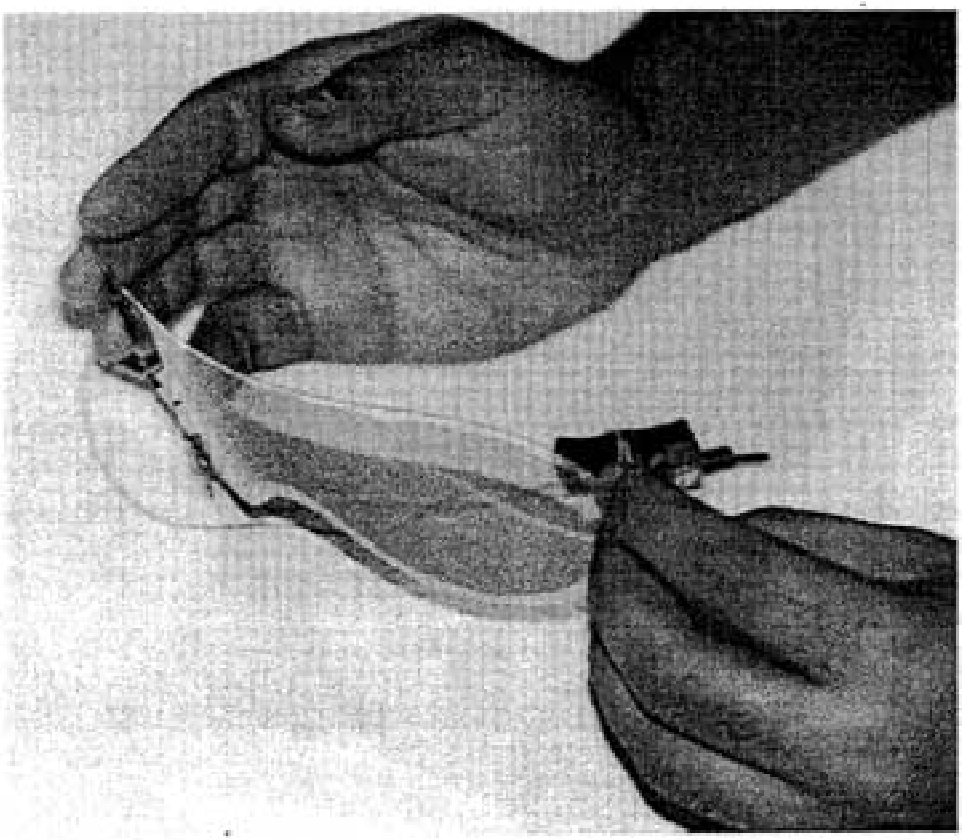


Figure 3. An FC-VALiD based system implemented on flexible substrate for use in SWD goggle.

Air Force visors, unlike the Army SWD goggles, are curved in both directions. There is a significant jump in moving from a cylindrical curvature to a double curvature. This is primarily due to the change in the area associated with a complex curve. Unlike the cylindrical cells, a flat cell cannot be made to fit a visor without significant alteration in its area. Therefore, it is not possible to use flat substrates to obtain FC-VALiD based VTVs.

To obtain doubly curved FC-VALiD, it was necessary to use two conformal substrates. This required a significant alteration in processing techniques. To develop these techniques, specially designed spherically shaped, conformal lenses coated with ITO were used. The spherical nature of the lenses allows for rotation symmetry during the assembly process. The two halves were tested for conformity prior to processing. It was found that, despite careful manufacturing conditions, the natural conformity was not within the tolerances required for liquid-crystal based devices. Thus, it was necessary to reshape the substrates to achieve conformity. In addition, novel processing methods had to be developed because conventional techniques such as spin coating are designed for flat substrates. These methods were developed and enabled us to implement FC-VALiD on spherical lenses with performance matching that obtained on flat glass.

Recently, we have been able to demonstrate, for the first time, implementation of a liquid crystal technology on doubly curved plastic substrates. A base-cap visor pair was purchased form AOtec LLC. Although the base-cap pairs are stackable, they are not conformal to within the tolerances required for liquid-crystal based technologies. Furthermore, the toroidal nature of the visors means that the processing techniques must also be rotationally sensitive. As with the lenses, the base-cap visor pairs were processed and forced to conform with a 1-micron tolerance. They were coated with low resistance ITO followed by our homeotropic alignment layer and assembled using 5-micron spacers. The visor assembly was then vacuum filled with the LC/dye mixture and sealed. Figure 4 shows the visor with FC-VALiD system. The system was tuned to allow a transmission range of 55%-15%. This window meets the requirement for daytime use by the pilots.

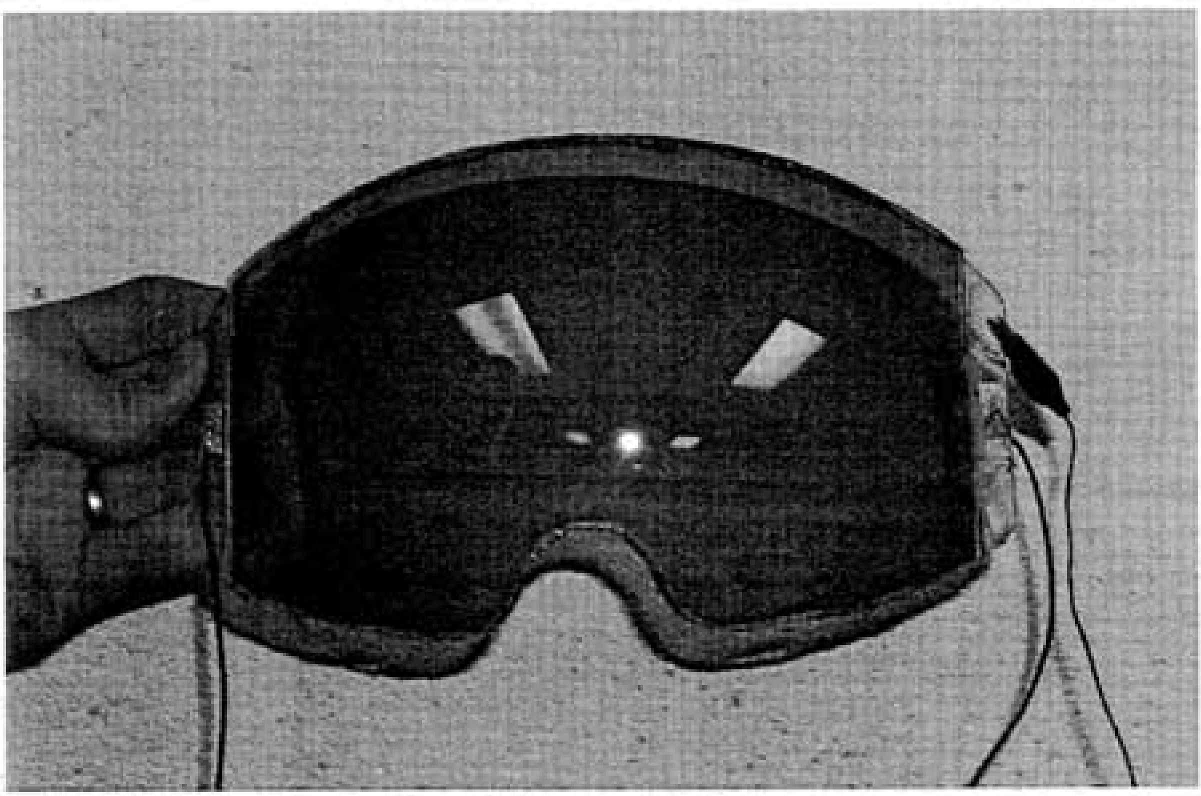


Figure 4. An HGU-55/P helmet visor with FC-VALiD system.

Although this system has been demonstrated, there are a number of issues that need to be addressed. In addition to materials performance, the conformality of the substrates is an essential feature of the device and requires tight control. This, along with the novel processing methods required, make it a challenging task to develop a completely controllable visor system. AlphaMicron is currently developing the processing steps needed for reliable production of these visors.

4. CONCLUSIONS

We have demonstrated a technology for use in VTVs. Liquid crystal can meet the requirements presented by the Air Force. In addition to a fails-clear configuration, the system can be implemented on plastic substrates. We have shown, for the first time, that it is possible to implement liquid crystal technologies on curved plastic substrates. This has been a fundamental limitation for liquid crystal technology. We are currently working toward optimizing the process for future manufacturing.

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